RESEARCH DEPARTMENT

THE VISIBILITY OF SMALL BRIGHTNESS DIFFERENCES IN TELEVISION DISPLAYS

Report No. T-083

(1962/6)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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SUMMARY

This report describes measurements of the smallest brightness difference which can be reliably identified in television displays. The amplitude of the brightness difference is plotted as a function of the brightness level at which it can be just recognized. An estimate is made of the number of discrete levels into which a television picture should be quantized in order to preserve an acceptable picture quality without an unduly large number of levels.

1. INTRODUCTION

Many of the methods proposed for the reduction of the channel capacity required for a television signal depend upon the quantization of the picture brightness. Various estimates have been published of the number of levels into which a television signal must be quantized in order to reproduce a picture satisfactorily. The work described in this report was carried out as part of an investigation[1] into the possibilities of such systems.

The upper limit for the number of levels required is that at which no difference between the quantized and unquantized pictures can be distinguished by eye. The smallest number of levels might be taken as that at which the outlines of all the essential items in the reproduced picture were recognizable.

The measurements to be described here were carried out in order to find the number of levels required to meet two separate demands. In order to maintain efficiency in the transfer of information the brightness difference between adjacent levels should not be less than the smallest difference capable of reliably conveying information to the viewer. On the other hand, if too few levels are used the picture quality will be marred by visible contour lines marking discontinuities of brightness in areas of the picture where such discontinuities should not occur. These contours are undesirable when they show quantization of the gradual changes of brightness which are essential for the realistic reproduction of pictures of three dimensional objects and scenes.

Two separate sets of measurements were made. In the first set viewers were shown displays of small numerals superimposed on a picture of Test Card "C". The difference between the brightness of the numerals and that of their immediate surround was adjusted in order to find the smallest difference at which the numerals could be identified. The second set of measurements was concerned with the smallest noticeable difference of brightness between two halves of the displayed picture.

2. EXPERIMENTAL PROCEDURE

The output signals from two television picture sources were added together and supplied to a 21 in (53 cm) picture monitor. One of the sources was a monoscope waveform generator producing a signal corresponding to Test Card "C". The second source was a flying-spot slide scanner. This was used to produce an image of a column of numerals which could be made to coincide with the squares forming the brightness step-wedge in the centre of the Test Card "C". The effect of adding the two waveforms and displaying the result on a picture monitor is shown in Fig. 1. The sequence of numerals could be changed and they could be shown as single numerals coinciding with any one of the five brightness squares. By changing the polarity of the scanner output waveform the numerals could be made to appear either lighter or darker than their surrounds. The scanner waveform was passed through an adjustable attenuator before being added to the Test Card "C" waveform. Thirty observers, in groups of five at a time, were seated between five and seven times the picture height in front of the 21 in picture monitor. These observers were asked to write down the numerals visible to them when presented at various ratios of the amplitudes of the two

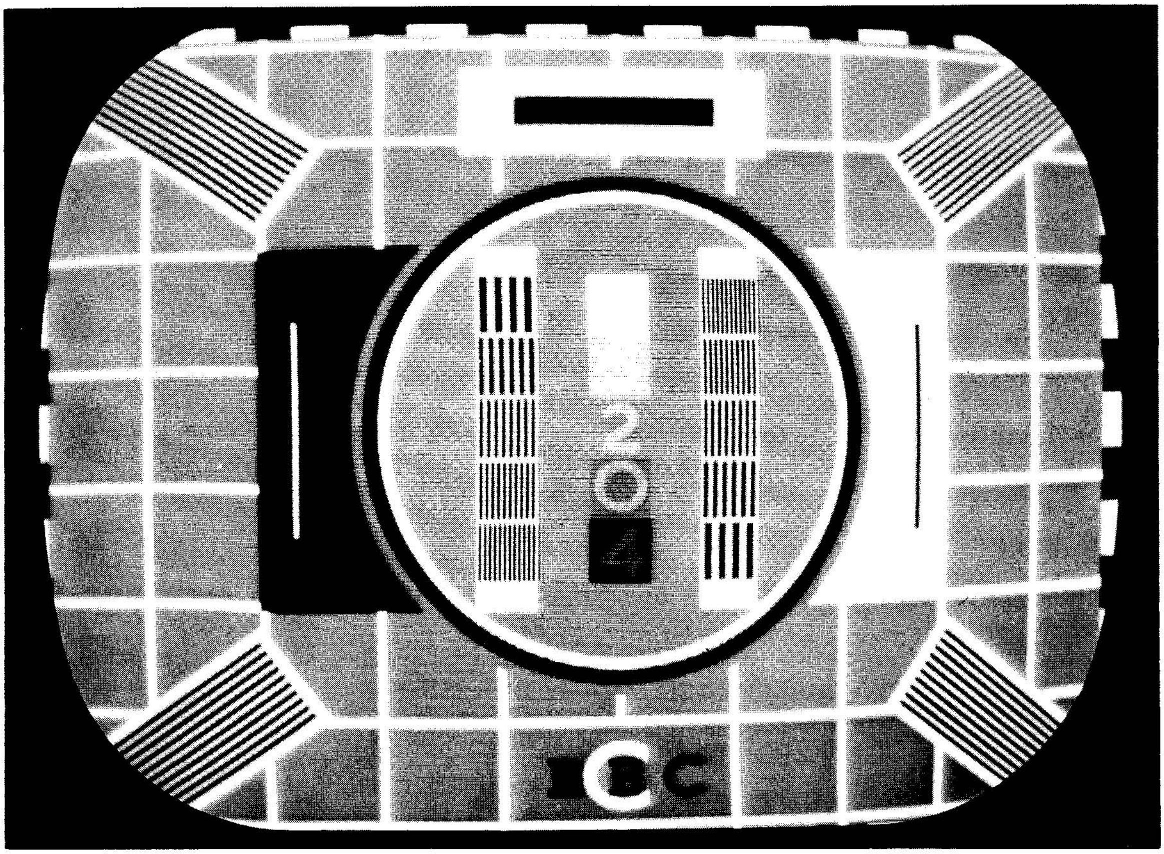

Fig. 1 - Test Card with numerals superimposed

waveforms. The proportion of numerals correctly identified was then recorded for the various ratios of the two waveform amplitudes at the various voltage levels of the test-card waveform corresponding to the five brightness levels in the step-wedge of the test-card picture.

The monitor screen was adjusted to the following brightness levels in the absence of the superimposed numerals:

peak-white square,	20 ft-L
light-grey square,	12 ft-L
mid-grey square,	5 ft-L
dark-grey square,	3 ft-L
darkest square,	0·3 ft-L
large black areas,	0·25 ft-L

The ambient lighting was such that the monitor screen, in the absence of phosphor excitation, reflected about 0·15 ft-L. A white card held in front of the monitor screen reflected a brightness of 0·35 ft-L. The brightness and contrast controls were adjusted so that no raster lines were visible in the large black areas of the test card. The difference in the brightness under these conditions (0·25 ft-L) and that when the monitor was switched off (0·15 ft-L) was apparently due to flare in the screen face. There was no extra glass in front of the cathode-ray tube for these tests. The brightness measurements were made with an S.E.I. photometer with a black tube extending from the instrument lens to the part of the monitor screen being examined. This was arranged in order to reduce error caused by flare introduced in the photometer when exposed to light from bright areas in close proximity to dark areas being measured.

Some extra measurements were made with the monitor adjusted so that the darkest square had a brightness of about 1 ft-L in order that results could be obtained for a brightness between the values of 0·3 and 3 ft-L.

In order to measure the effect of random noise in masking the brightness discontinuities, the tests were repeated with noise added to the waveforms at the monitor input. The noise came from a high quality vestigial-sideband receiver fed with an unmodulated carrier, and was adjusted to have an r.m.s. value 27 dB below the peak-to-peak (black-to-white) video waveform of the test card. Further measurements were made to find the effect of restricting the time permitted for recognition of the numerals superimposed. For this the numerals were presented singly instead of in columns of five and for one second only. The observers were previously told in which brightness square the numeral would appear and they were asked to record individually which numeral they thought had been superimposed. In all these experiments the test card remained continuously displayed on the monitor screen so that the adaptation conditions were not changed during the tests.

A second set of experiments was carried out in order to measure the visibility of brightness discontinuities not directly related to picture content and not even conveying useful information. The same apparatus and procedure was used except that straight-line discontinuities of brightness were superimposed instead of the numerals. The slides which were used to produce these discontinuities were each divided into two equal areas of which one was transparent and the other opaque. The waveforms produced with these slides were added to that of the test card and caused one half of the displayed picture to have a different mean brightness from the other. The line dividing the two brightnesses was vertical in one slide, horizontal in another and diagonal in a third. The result of superimposing such a pattern on the test card is shown in Fig. 2. By reversing the third slide a choice of two diagonals was available. The ability to reverse the polarity of each waveform provided eight different patterns for superimposing on the test card. The observers were asked to illustrate the pattern observed at each test by shading in squares on forms provided for this purpose.

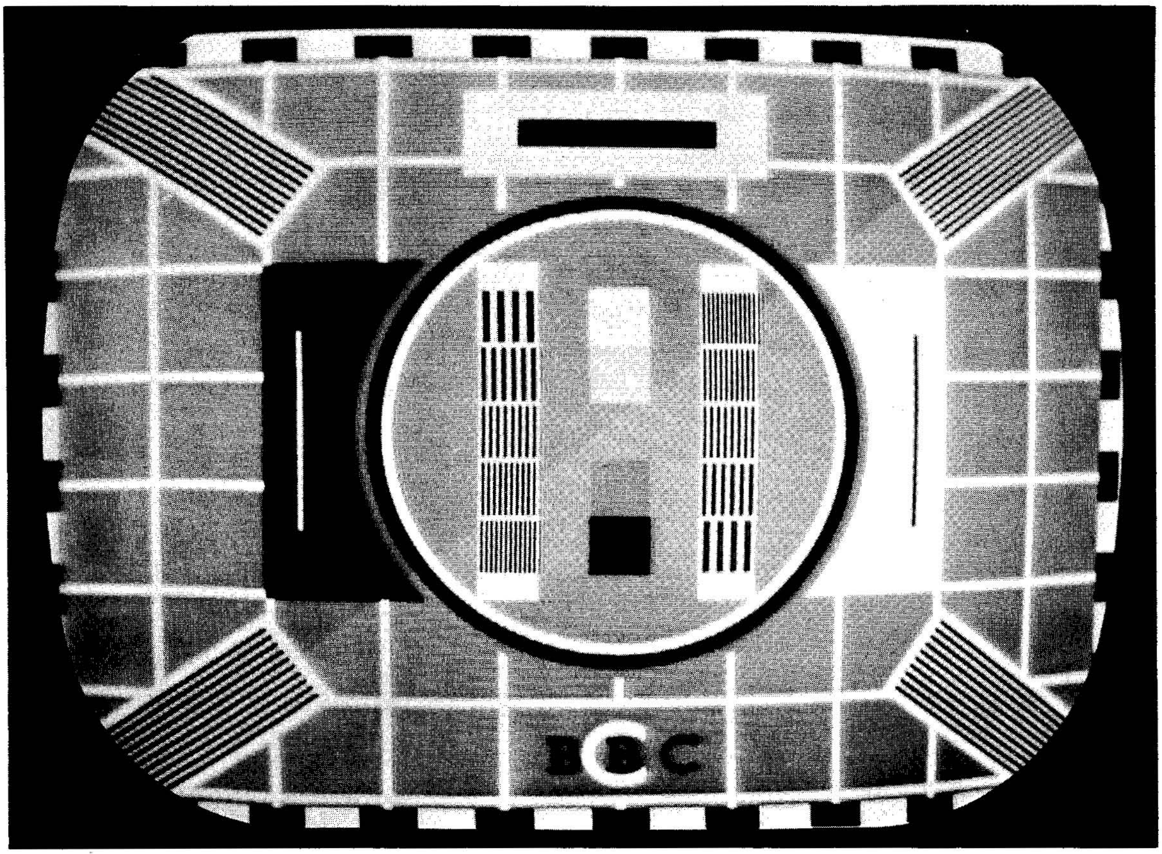

Fig. 2 - Test Card with pattern superimposed

3. EXPERIMENTAL RESULTS

The results of the tests using numerals are shown in Fig. 3. The Test Card "C" waveform was adjusted to have an amplitude of one volt for peak white and zero for black. The amplitude of the superimposed signals which produced 50% correct recognitions is plotted in Fig. 3 as a function of the particular voltage level upon which the numeral was superimposed. When the numerals were exposed for only one

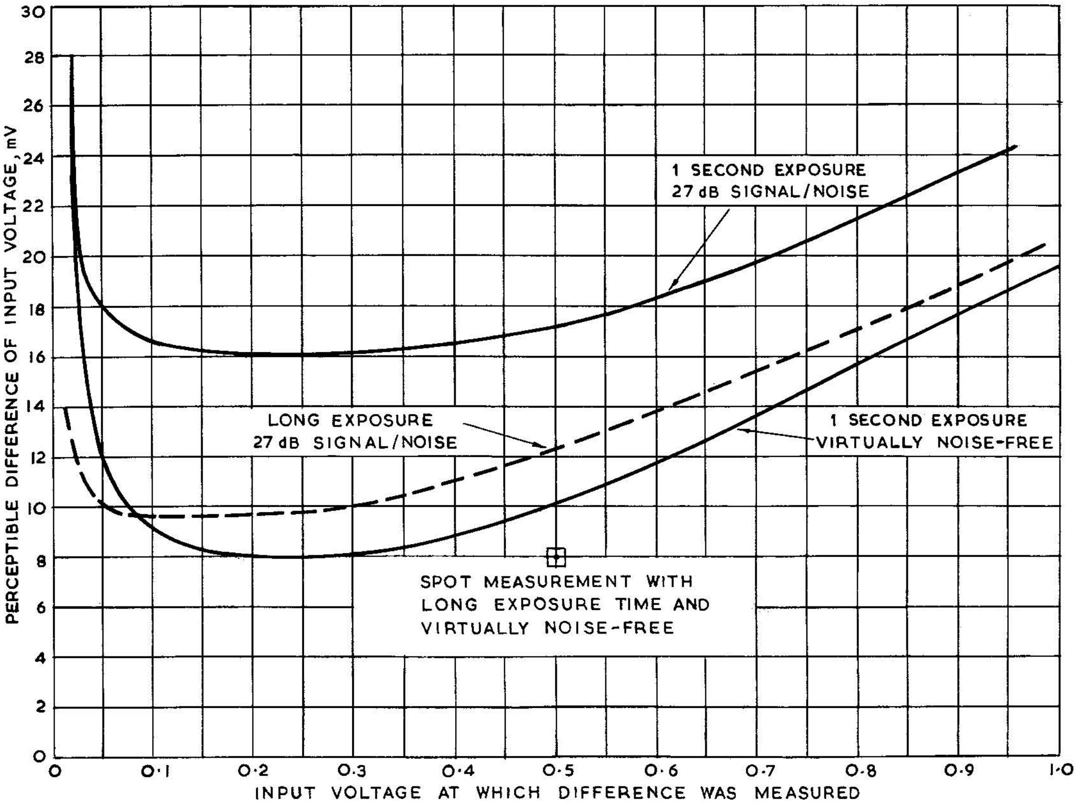

Fig. 3 - Video voltage amplitudes for numerals having fifty per cent recognizability

second, the effect of adding random noise was to increase the required amplitude of the "numeral" waveform by as much as two to one for some brightness levels in order to maintain 50% correct recognition. The effect of increasing the exposure time, to many seconds, was to increase the apparent visibility of the numerals. In these conditions 50% recognition could be obtained with the "numeral" waveform reduced to 1/1·6 of that required with the one-second exposure time. Measurements were made at the mid-grey level to find the effect of increasing the exposure time in the noise-free condition. These showed that the "numeral" waveform could be reduced to 1/1·25 of that required for the one-second exposure in the noise-free condition. It was found that the proportion of correct identification increased to 90% when the waveform of the superimposed numerals was increased by about 1·5:1 in all conditions.

For the second experiment, using the straight-line brightness discontinuity, it was found that a discontinuity, or step waveform, of 10 millivolts superimposed on the 1 volt test-card waveform produced 50% correct recognition with noise-free conditions. When the random noise was added to the displayed waveforms it was necessary to increase the step waveform to 17 millivolts. In both these cases the number of correct recognitions fell to 20% if the step-waveform amplitude was halved.

4. DISCUSSION OF RESULTS

From the results of the measurements we can compute the number of levels into which a television signal should be quantized in order to include all the detail which has at least a 50% chance of being recognized. This is based on the assumption that such detail can be represented by a single numeral which is completely contained within ½ to ¾ of one degree of arc subtended at the observer's eye, the sharpness of the edges of the numeral being restricted only by the 3 Mc/s cut-off frequency of the system. If we assume that the intervals between the brightness levels, i.e. the quantum size, is a function of the actual voltage level as indicated in Fig. 3 we can obtain the following results.

In order that details reproduced by the smallest possible brightness difference shall have at least a 50% chance of being recognized within one second with "fringe-area" reception the number of levels in a quantized television picture should not exceed 54 levels. If a greater number of levels was used, any extra detail which might be reproduced would be visible to less than half the viewers. In noise-free reception conditions smaller brightness differences can be noticed and 90 levels can be used. If it is considered essential that the smallest brightness difference shall have at least a 90% chance of recognition the number of levels must not exceed 36 for noisy reception conditions and 60 for relatively noise-free conditions. If the waveform were quantized into discrete levels of brightness the number of levels necessary, in order that the unwanted edge contours should not be visible more than 50% of the time, can be computed from the results of the tests using the large patterns. The discontinuity for 50% visibility in noise-free conditions was 1% of the peak video voltage; for the "fringe-area" noise conditions this figure was 1·7%. Inspection of Fig. 2 shows that the discontinuity was mainly visible against the mid-grey background which had a brightness of 5 ft-L and a voltage of 0·5 volts. These results agree with the amplitude of the small pattern (numerals) waveform at the same brightness level, as shown by Fig. 3. If we assume that the visibility of the unwanted contours varies with brightness in the same manner as the visibility of small patterns, the same number of levels will be required for a 50% visibility of both pattern sizes. For the noise-free condition, this would be 90 and for the "fringe-area" conditions, 54 levels would be required. In order that the unwanted edge contours shall be unnoticed at least 80% of the time, the number of levels required must be doubled.

Fig. 4 shows the measured relationship between brightness of the monitor screen and voltage of the video input. Fig. 5 shows the computed "point gamma" curve for the monitor used. Fig. 6 shows the information in Fig. 3 replotted in terms of percentage brightness instead of voltage. It will be observed that for the brightness range between 3 and 20 ft-L the percentage brightness change is constant. This is an interesting confirmation of Weber's Law for the case where the

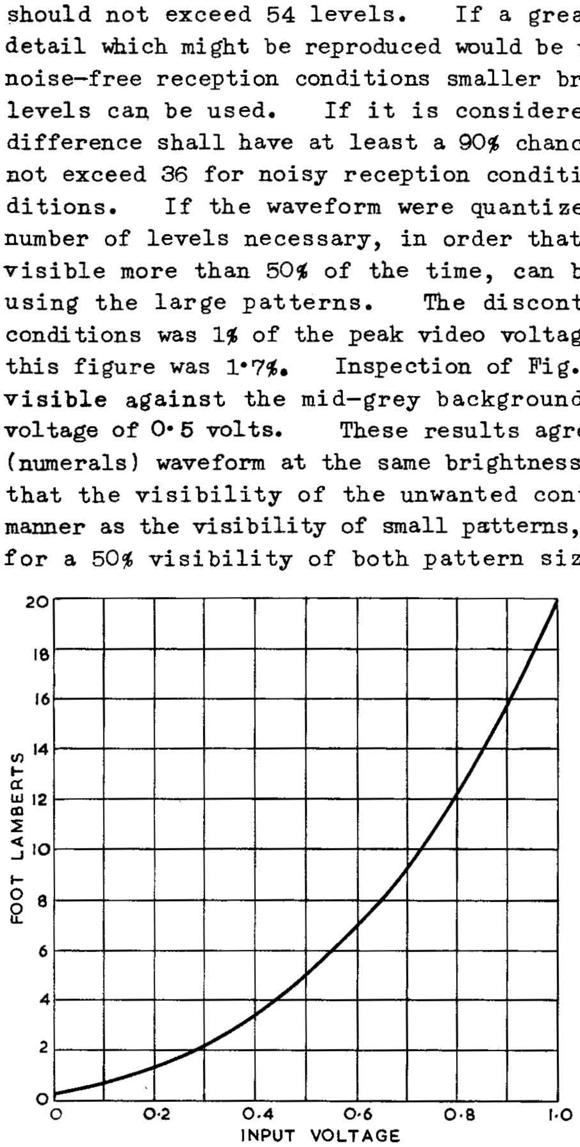

Fig. 4 - Brightness/Voltage characteristic of monitor

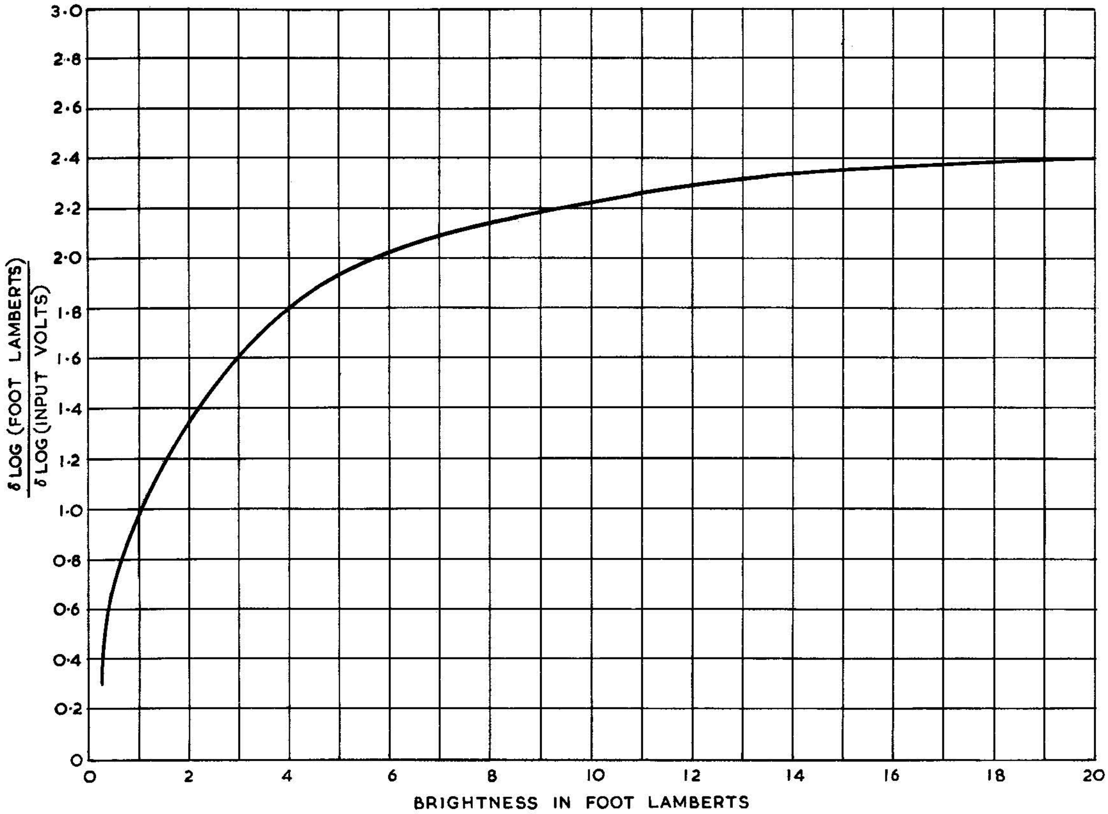

Fig. 5 - "Point Gamma" characteristic of monitor

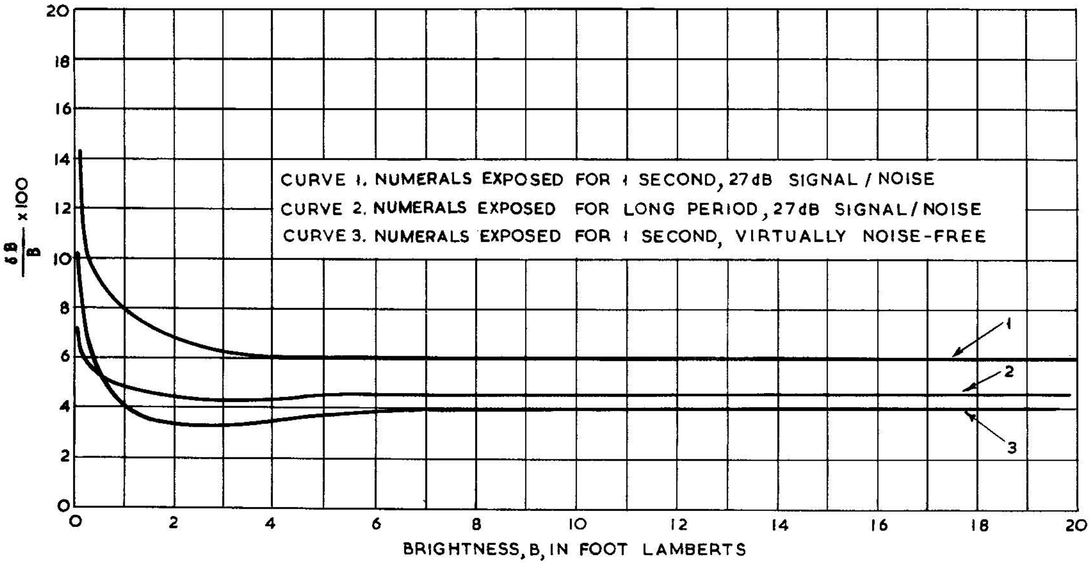

Fig. 6 - Percentage change of brightness as a function of brightness

entire area of brightness change is contained within 45 minutes of arc at the viewer's eye while the aperture of the viewer's eye is almost entirely determined by the unvarying brightness of the surrounding picture of a test card. The deviation from Weber's Law in the dark areas of the picture confirms the results published by Billard[2] although his conditions were somewhat different.

It was noticed that when the amplitude of the numerals waveform was reduced until the observers gave incorrect answers, these incorrect answers often appeared consistent and apparently repeatable. Examination of the voltage waveform of the test card showed that what had previously been accepted in the step-wedge as squares of uniform brightness included consistent voltage variations having peak-to-peak values of as much as 40 millivolts in the mid-grey square and the dark-grey square and as much as 30 millivolts in the other squares. The visual appearance of these variations was a stationary pattern of irregular textural quality superimposed on the test card. This non-uniformity was not normally noticeable, but was sufficient to distort or modify the outline of the superimposed numerals when these were of small amplitude. From this it might well be concluded that the limit of visibility of the superimposed numerals was largely determined by this irregular textural background. This may well be the case, because the brightness variations caused by this irregular pattern had a peak-to-peak value of as much as 8% of the mean brightness in the immediate area. The non-uniform background which was due to imperfections in the monoscope target is not untypical of television picture sources. Measurements of some slide scanners and camera channels showed that variations of almost as much as those measured in the monoscope could easily occur in these other picture sources.

5. CONCLUSIONS

The measurements show that, with normal television displays in "fringe-area" conditions of noise level, small-area detail has at least a 50% chance of being correctly recognized within one second if it has a brightness which is different from that of its immediate surround by not less than 6%. In relatively noise-free conditions, and without restriction of time, this figure drops to 4%. If the peak brightness of the display is set to 20 ft-L the percentage differences are independent of the immediately surrounding brightness down to a value of 3 ft-L. For areas of picture brightness less than 3 ft-L the percentage required is larger.

The maximum number of levels in a quantized waveform to ensure a 50% chance of recognizing the smallest amplitude detail within one second is 54 for noisy reception conditions and 90 for noise-free conditions. These numbers must be reduced by one third if a 90% chance of correct recognition of the smallest amplitude of detail is required.

In order that the unwanted brightness discontinuities produced by quantizing a gradual change of video waveform shall not be apparent on 50% of occasions, with noisy reception conditions, at least 54 levels are required. In relatively noise-free conditions this figure must be increased to 90 levels.

From these conclusions it would appear that 90 levels would produce a good compromise for noise-free reception of a quantized picture and that 54 levels would suffice for "fringe-area" reception conditions.

6. ACKNOWLEDGEMENTS

The authors are indebted to their colleague Mr. K.J. Wright for his help in carrying out these measurements.

7. REFERENCES

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